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Frequency domain multiplexing for bolometer arrays

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Abstract

Fabrication of arrays of a thousand or more sensors is becoming practical. However, readout of these arrays remains a major instrumental challenge. We address this challenge using frequency-domain multiplexing of signals from an array of superconducting transition-edge sensors (TES). Each TES sensor is connected in series with an LC tuned circuit and biased with an alternating current at a selected frequency, ranging from 380 kHz to 1 MHz.The signal from each sensor amplitude-modulates its respective bias current. The LC filter reduces the bandwidth of the Johnson noise from the remaining sensors. The signals are combined at a current summing node and measured with a single superconducting quantum interference device (SQUID) array (100 elements). We have developed a custom SQUID controller with a measured slew rate of $10^7\,\Phi_0$/s at 1 MHz.

We designed and fabricated photolithographed LC filters. With these filters we have demonstrated multiplexing with two TES sensors and are preparing to scale up to 32 sensors.

Keywords: Bolometer; Transition-edge; Multiplexer; SQUID

1. Introduction

New cosmic microwave background (CMB) observations will achieve higher sensitivity with large arrays of several hundred to several thousand bolometers. The development of voltage-biased superconducting transition edge sensors (TESs) with strong electro-thermal feedback is a key technology that provides well-controlled operating points and stable responsivity over large arrays [1,2]. A second key technology is the development of fully lithographed fabrication techniques [3]. The remaining challenge is the readout of large arrays. To reduce readout complexity and heat load to subkelvin stages the sensor signals will be multiplexed in either the time-domain [4,5] or the frequency-domain [6,7]. This paper discusses the development and testing of a frequency-domain multiplexer for transition-edge sensors.

2. Basic design

We operate transition-edge sensors with an AC bias. When the sensor absorbs optical power, its

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resistance changes and the AC bias is amplitude modulated. The signal is carried in sidebands above and below the bias frequency. We use a SQUID array to detect the bias currents. Each multiplexed sensor has a different bias frequency and thus sensors are separated in frequency space. The currents are summed and reach the SQUID via a common readout line. Room temperature electronics are used to demodulate each sensor signal. We can read out arrays of hundreds to thousands of sensors by using many multiplexer units, each reading out approximately thirty sensors.

Each sensor contributes broadband Johnson noise. We introduce an LC filter in series with each sensor to limit the bandwidth of each channel, as shown in Fig. 1. The LC filter also allows us to send a "comb" of different bias frequencies. Each filter selects the correct bias frequencies and blocks the others.

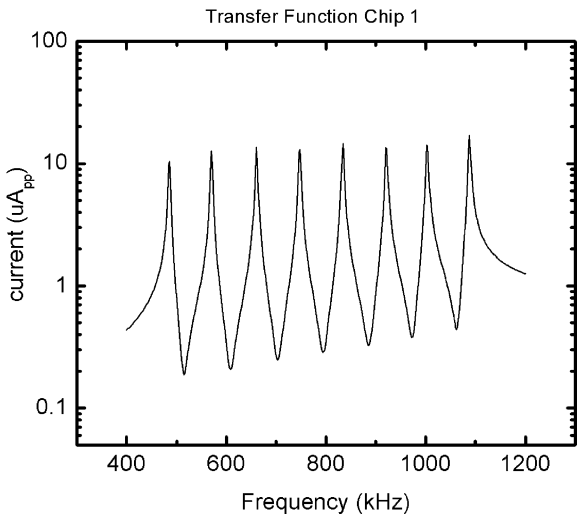

Fig. 2. Transfer function of LC filter chip connected to 0.5 Ω resistors.

3. LC filter chip

We designed a 32-channel multiplexer using the configuration of Fig. 1. TRW fabricated 4 sets of LC filter chips. Each chip has eight LC filters with four times the nominal spacing of 20 kHz. Filter chips can be wired in parallel for up to 32-channel multiplexed channels. The frequency range is from 380 kHz to 1 MHz.

The filter inductors consist of spiral coils on top of a slit square washer [8]. The capacitors use Nb_2O_5 as a dielectric.

We measured the transfer function of the LC filters, each connected in series with 0.5 Ω, at 4.2 K to verify the chip parameters (Fig. 2). The Q value of each LC filter is lower than the design goal due to losses in the capacitor dielectric, Nb_2O_5. The loss factor is $\delta = 0.0030 \pm 0.0005$ for each channel. We are planning a new fabrication run in which we will change the dielectric to SiO_2.

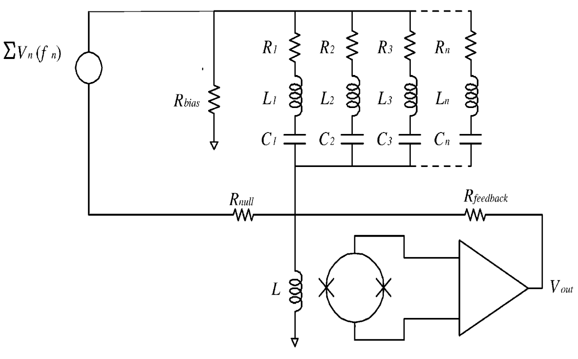

Fig. 1. Diagram of multiplexed readout circuit.

4. SQUID controller

To measure multiple bias currents from each sensor with sufficient dynamic range, we need a high slew rate SQUID controller. We have achieved a slew rate of $10^7 \Phi_0$/s with a custom controller and a SEIKO 100-element series array SQUID.

We use a single operational amplifier (AD797). The single pole gain roll-off of the amplifier controls the phase shift of the feedback. To ensure feedback stability, the phase shift of the feedback should be dominated by the amplifier. Wire lengths between the room temperature electronics and the SQUID need to be < 10 cm to minimize phase shifts from propagation delay [9].

The feedback current signal is applied to the same coil of the SQUID as the sensor signals. This "shunt" feedback effectively reduces the input impedance of the SQUID controller so the sensors remain voltage-biased.

Since the sensor information is carried in sidebands above and below the sensor bias frequency, the bias current can be nulled at the SQUID coil, thus reducing the required dynamic range of the SQUID controller for a given number of channels. We estimate that with carrier nulling and the current slew rate of our SQUID controller, we can multiplex up to 32 channels.

5. Testing MUX with TES

We have operated two sensors with our LC chip and shunt feedback controller with a NIST 100-element series array SQUID. The sensors were biased at 671 and 735 kHz. I–V curves for sensors under AC bias match those for sensors under DC bias. We stepped the AC bias level of each sensor and saw the expected demodulated change for each sensor.

We measured the system noise at 4.2 K with the two sensors in place. Both sensors are normal at 4.2 K and have a resistance of 1 Ω. The noise from each sensor easily overrides the system noise.

6. Conclusions

We have fabricated LC filters with photolithographic techniques. In addition, we have demonstrated a current summing frequency domain multiplexer with two sensors.

Our next steps will be measuring the cross-talk between neighbour channels, characterizing the noise of each multiplexed sensor, and increasing the size of our multiplexer to 32 channels.

Acknowledgements

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